Presentation Information:

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Title:

MPI, HPF or OpenMP -- A Study with the NAS Benchmarks†

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Abstract:

Porting applications to new high performance parallel and distributed platforms is a challenging task. Writing parallel code by hand is time consuming and costly, but this task can be simplified by high level languages and would even better be automated by parallelizing tools and compilers. The definition of HPF (High Performance Fortran, based on data parallel model) and OpenMP (based on shared memory parallel model) standards has offered great opportunity in this respect. Both provide simple and clear interfaces to language like FORTRAN and simplify many tedious tasks encountered in writing message passing programs. In our study, we implemented the parallel versions of the NAS Benchmarks with HPF and OpenMP directives. Comparison of their performance with the MPI implementation and pros and cons of different approaches will be discussed along with experience of using computer-aided tools to help parallelize these benchmarks. Based on the study, potentials of applying some of the techniques to realistic aerospace applications will be presented.

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* Employee of MRJ Technology Solutions.

Note:

Only the above abstract is being submitted for Document Availability Authorization at this time. The slides of the full talk will be completed and submitted for DAA at a later date.

MPI, HPF or OpenMP -- A Study with the NAS Benchmarks

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http://science.nas.nasa.gov/Groups/Tools/Projects/LCM/

Overview

- Motivation
- NAS Parallel Benchmarks (NPB)
- Programming Baseline for NPB (PBN)
- HPF Implementation
- OpenMP Implementation
- Performance Comparison
- Remarks

Motivation

High performance computing
- evolving and expensive
- code porting costly, time-consuming

Popularity of MPI
- high performance and widely supported (portability)
- but, hard to program, prone to error

Alternatives
- computer aided tools and translators
- data parallel languages
- parallelizing compilers

Goal
- examine the effectiveness of HPF and OpenMP vs. MPI
- using NPB as a test suite

Programming with MPI

Data partition
- how data be distributed
- domain decomposition strategy

Computation distribution
- independent loops and code sections
- computation masking

Data communication
- when data needed but not available

... downside
- no incremental approach
- low-level, hard to write

High Performance Fortran (HPF)

Data parallel language approach

- parallelization based on data distribution, *owner-computes-rule*
- user-added directives to distribute data and parallelize loops

Strength

- built on top of a high-level language, easy to program
- portability from the HPF standard

Weakness

- questionable performance due to immaturity of compiler technology
- hidden performance model, hard to track
- lack of handling irregular computation

OpenMP

An industry standard for SMP

- computation based on shared-memory model
- compiler-directives to parallelize loops and independent code sections
- *fork-and-join* model

Strength

- offered incremental approach to code parallelization
- high-level constructs, easy to program
- portable for SMP, good performance

Weakness

- hidden data distribution
- not for distributed memory system

NAS Parallel Benchmarks

8 problems, 5 class (S, W, A, B, C) sizes

- derived from *CFD* applications
- specified *algorithmically*, not by source code

3 pseudo-applications

- BT Independent Block(5x5)-Tridiagonal systems
- SP Independent Scalar-Pentadiagonal systems
- LU Lower-Upper symmetric Gauss-Seidel

5 kernels

- FT spectral method (FFT) to solve Laplace equation
- MG MultiGrid method to solve Poisson equation
- CG Conjugate Gradient method
- EP random-number generator (Embarrassingly Parallel)
- IS Integer Sort

NPB 2

Source code implementation

- with MPI communication constructs
- coded in Fortran 77, except IS (C)
- optimized generically, not for specific machines
- demonstrate real-world performance for portable user codes

NPB 2.3-serial

- stripped-down versions of the MPI implementations
- as *starting points* for other implementations and for performance test of parallelizing tools/compilers

Programming Baseline for NPB (PBN)

What is PBN

- based on NPB2.3-serial
- additional modification
  - real-world user optimization of the serial codes
  - memory optimization in BT and SP
  - hyper-plane and pipeline algorithms in LU
  - data-copy improvement in FT and IS
  - more convenient timers

Why PBN

- provide the optimized version of NPB2.3-serial
- make it available for public
- distinguish from the official NPB
- give sample HPF/OpenMP implementations

In Our Study

Starting point

- benchmarks from PBN-Serial
  - BT, SP, LU, FT, CG, MG
  - excluded EP (for HPF) and IS (for HPF & OpenMP)

Implementations

- HPF sample implementation (PBN-H)
  - done by hand
- OpenMP sample implementation (PBN-O)
  - created by hand with assistant of parallelizing tools

HPF Implementation

Data distribution

- with `ALIGN` and `DISTRIBUTE` directives

Expressing parallelism

- F90 style of array expressions
- `FORALL` constructs
- `INDEPENDENT` directive for loops
- HPF library intrinsics

Data redistribution

- to overcome incapability of multiprocessor pipelining and lack of the `REDISTRIBUTE` directive
- needed in BT, SP, and FT
- extra arrays used to keep the redistributed data

OpenMP Implementation

Parallel loops and sections

- with "`!$OMP PARALLEL DO`" and "`!$OMP PARALLEL`"
- outer-most loops for large granularity and low overhead
- no consideration of independent code sections

Variable privatization

- list local variables in the "`PRIVATE()`" construct
- avoid conflict of memory access and false sharing

Point-to-point synchronization

- for multiprocessor pipeline implementation in LU
- with the "`!$OMP FLUSH`" construct

Others

- data distribution based on the *first-touch* model
- no need for redistribution, thus, no extra arrays

Testing Environment

SGI Origin2000 (distributed shared memory)

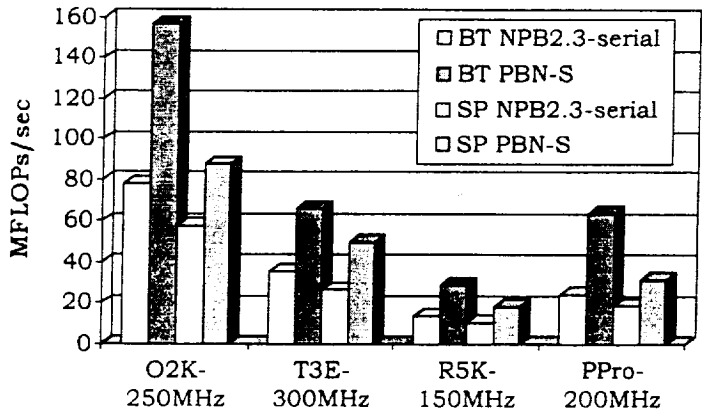
- CPU: 195MHz, 32KB L1 cache, 4MB L2 cache
- compilers
  - MIPSpro-f77 compiler 7.2.1
  - PGI pghpf-2.4.3 compiler with MPI interface
- versions tested
  - NPB-MPI, PBN-H and PBN-O

Cray T3E-1200 (distributed memory)

- PE: 300 MHz, 128MB
- compilers
  - Cray-f90 compiler 3.1
  - PGI pghpf-2.4.3 compiler with SHM interface
- versions tested
  - NPB-MPI and PBN-H

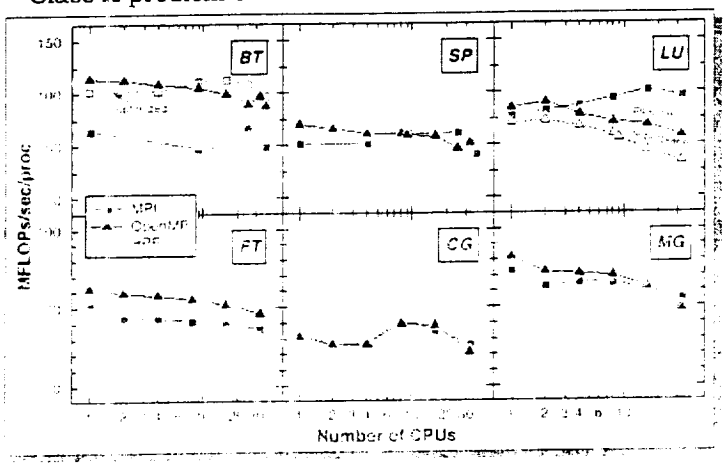
PBN-S vs. NPB2.3-serial

- Single processor, four different platforms
- Class **A/W** problem size



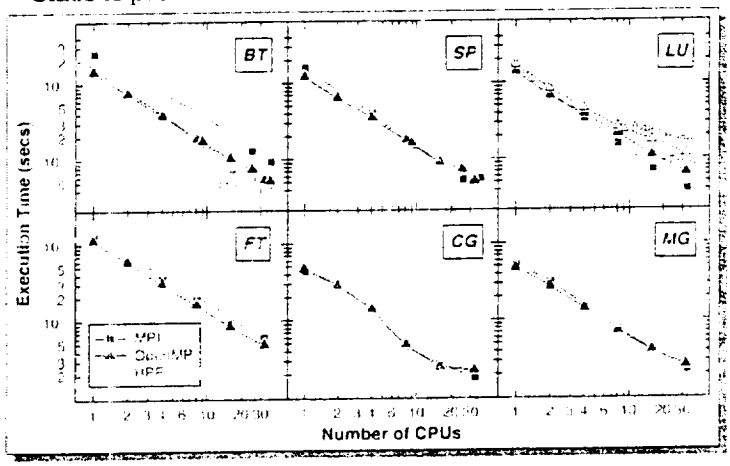
Parallel Performance (Mflops)

- On SGI **Origin2000**, 195MHz
- Class **A** problem size



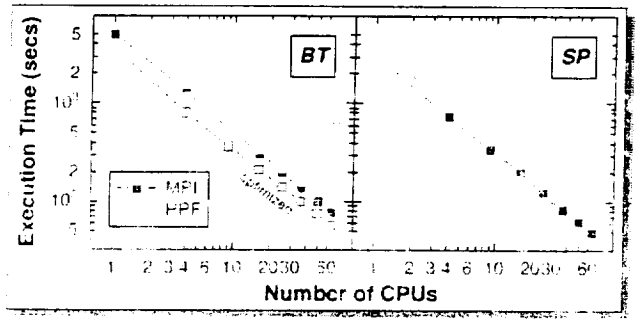
Performance Comparison (Time)

- On SGI **Origin2000**, 195MHz
- Class **A** problem size



Performance Comparison (Time)

- On Cray **T3E-1200**, 300MHz
- Class **A** problem size



Remarks

Overall, MPI implementation scaling the best

- multi-dimensional partition
- good load balance

OpenMP performing quite well

- close to MPI in most cases
- even better in FT, no data transposition
- but, 1-D multiprocessor pipeline in LU not as good
- yet to see on larger number of processors

Remarks-Cont.

HPF catching up, but still behind

- closer to MPI in FT and CG
- BT and SP closer to MPI on Origin2000, but deviated quite a bit on T3E and even flat out after 32 procs
- poor performance of MG related to the lack of handling irregular computation in HPF

Serial optimization

- affects overall performance
- optimized BT as an example

Conclusion

Echo back

- MPI hard to program, OpenMP easy to write
- lack of HPF performance model still evident
- multi-level parallelism in OpenMP not quite supported

Future development

- maturity of HPF compilers
- better tools and compilers help ease
  - the writing of MPI programs
  - even useful for OpenMP/HPF programs
- on our part
  - tests of PBN-H/PBN-O on more platforms
  - program development environment

Integrated Parallelization Environment